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INSMART – Insights on integrated modelling of EU cities energy system transition

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ABSTRACT

Urban areas have a pivotal role to play in climate change mitigation, as they are responsible for a high share of energy consumption and provide many opportunities for more efficient supply & use of energy. This makes the case for energy system modelling at city level, as done within the INSMART EU project, which identified the optimum mix of measures for a sustainable energy future for four European cities in a holistic manner. The approach combined quantitative modelling with Multi-Criteria Decision Analysis. Sector specific data and models (buildings and transport) were articulated into one integrated energy system model based on the TIMES model generator. It was found that urban level energy modelling brings with it a new set of challenges, since for a well-known territory, transparency and effective communication with local decision-makers are even more important than at national or transnational level. Special efforts should be paid to making model results geographically explicit, and urban modelling results should expect scrutiny by local agents. It was found that there is a gap between the scope for action of local energy planners and the most energy intensive urban sectors, which highlighted new priorities instead of those traditionally taken under municipal management.

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1. Introduction

Approximately 72% of the European Union (EU) population lives in urban environment (cities, towns and suburbs) [1]. Globally, an estimated 55% of the population currently lives in urban settlements, and this share will increase to 60% in 2030 according to United Nations (UN) projections [2]. Across the globe, cities consume 78% of the world's energy and are responsible for more than 60% of global CO_2 emissions, due to energy generation, transport, industry, and biomass use [3,4]. In the light of EU and national governments commitments to respond to the threat of climate change [5] and [6], the role of cities is gaining prominence. Not only are cities responsible for a significant share of greenhouse gas (GHG) emissions, they also provide many opportunities for more efficient generation, distribution and use of energy [4], as they centralise market power for innovation in general [7].

Acknowledging the pivotal role that urban areas should play in climate change mitigation, there are several city-led initiatives, such as the EU Covenant of Mayors Pact (CoM) [8](currently renamed as Covenant of Mayors for Climate & Energy following the merge of the CoM and Mayors Adapt initiatives), the UN Compact of Mayors [9], or the C40 Cities Climate leadership group [10], that commit to lead their partner cities towards sustainable development achievements, low carbon future design and improved quality of life of their citizens. These cities initiatives are mostly voluntary and face barriers such as lack of resources, capacity in terms of technical preparedness as well as competence, and also political prominence [11]. A review of 200 EU cities' climate plans concludes that climate change planning in European cities is more a function of "local organisational capacity rather than proactive anticipation of future need" [12,13]. Most of the city plans (both on

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climate and on sustainable energy) are developed by the cities following a relatively simple methodology recommended by organizations as the CoM or Compact of Mayors. The CoM methodology includes completing a GHG inventory with a breakdown of emissions for buildings, transport sectors and waste, commit to a GHG reduction target and to develop a city's strategic action plan showing how it will deliver on its commitment to reduce GHG emissions and adapt to climate change (e.g. Sustainable Energy Action Plans or SEAP) [9], [14]. In many cases this results in a piecemeal approach where each sector is considered individually and GHG emissions or energy savings are summed to obtain one overall city target. In other words, sustainable energy plans are not usually supported by an integrated energy planning approach, where different alternative city development options are compared [15]. Nonetheless, several authors state the added value of comprehensiveness in the city planning process towards sustainable energy [16–18], and a few authors have presented different perspectives and models for simulating future cities and its energy planning in a more integrated manner (e.g. Refs. [19–24]) or using complementary approaches such as Multicriteria Decision Aid [25] or web based tools for optimisation of alternative scenarios [26].

In this paper, we present insights on modelling in an integrated manner the transition of the energy system in four EU cities gained while developing and implementing an approach for planning cities' sustainable energy futures, within the European project INSMART. The paper is organized in four sections as follows: a brief overview of the methods is presented in Section 2, the insights on integrated modelling of the energy system transition of EU cities are presented and discussed in section 3, and Section 4 concludes.

2. Methods

The EU FP7 funded INSMART [27–29] project has developed a process to enable European cities to plan their future energy use more sustainably. This process has been tested with four European cities – Trikala (Greece), Cesena (Italy), Évora (Portugal) and Nottingham (United Kingdom) in close articulation with the municipalities concerned and has been supported by a range of technical specialists from the four countries. A brief characterisation of the cities is included in Table 1, highlighting their varied population, area and energy use profiles. The INSMART process (depicted in Fig. 1) included the following city sectors: residential and services buildings (privately owned and managed by the municipalities), public and private transport, urban spaces (green areas, public lighting) and city support services (water, waste water and waste management). The cities energy supply side regarding potential for intra-city renewable energy generation was also included to have a full comprehensive city energy system (e.g. photovoltaic or PV, solar thermal, small-scale hydropower, wind, geothermal and biogas). The imposts of energy (electricity, natural gas, biomass, liquid fuels) into the city were also considered, including associated GHG emissions. An average national GHG emission factor was considered for these imports and kept constant till 2030. The analysis focused the years of 2020 and 2030. It started with collecting local data of multi-scale granularity (e.g. 15 min electricity consumption registries from smart meters [30,31], monthly to annual statistical energy production and consumption data, door-to-door surveys).

The data was used to characterise the base-year situation in the cities, which allows developing future urban energy scenarios and comparing their sustainability with the base-year situation. The drivers for 2030 scenarios consider evolution of population and number of dwellings, modifications in energy consumption patterns (e.g. higher thermal comfort requirements in buildings or different mobility patterns), which are also associated to development/modification of residential, industry or services areas within the city. The types of scenarios selected by the cities varied from the implementation of specific actions as refurbishment of residential buildings to more comprehensive scenarios focusing on urban regeneration. The compiled data was input into state-of-the art sector modelling tools for buildings (Energy Plus) and transport (Design Builder), used both to perform detailed energy modelling of buildings archetypes and energy efficiency measures impact (e.g. GJ energy saved by implementing cavity wall insulation in residential archetypes), as well as of city (public and private) transport characteristics and mobility flows (e.g. effect of lowering driving speeds in some city zones), and to support the development of plausible future transport and buildings energy scenarios. The resulting sector scenarios for each city were then run through the International Energy Agency's TIMES integrated energy system optimisation model. TIMES models optimise the portfolio energy supply and demand technologies that satisfy the energy service needs with lowest total system costs [32]. TIMES was used as a city planning platform to identify in an integrated manner the urban energy system scenario's effects in terms of energy consumption, GHG emissions, share of renewable energy and energy costs. The TIMES scenarios were tested and ranked through a Multi-Criteria Decision Analysis (MCDA) approach to ensure the scenarios are economically, environmentally and socially acceptable while improving economic prospects and quality of life. The MCDA entailed the active participation of local stakeholders, namely: regional government authorities; local authorities (municipality and sub-municipal management); market agents (PV companies, business associations, waste company) and non-governmental organizations (e.g. university, consumer associations and environment protection). The stakeholders in each city selected the qualitative and quantitative criteria to use in the MCDA and respective weights. Examples of criteria used were: reduction of energy consumption or of GHG emissions, financial efforts required, social acceptability or bureaucratic complexity The performance of each scenario for the quantitative criteria was obtained from the TIMES model results. For the qualitative scenarios, the stakeholders classified the scenarios in one of the participatory workshops. The scenarios were ranked using the Hinkel's method to determine the weights of the objective function.

As a final step, each municipality used its highest ranked scenarios to develop a realistic city-level energy action plan over the next decade. Some of the results achieved with these plans for each city are presented in Table 1. These results in energy savings and CO_2 emissions reductions were obtained using the MCDA to rank the results scenarios modelled in the TIMES city models. . Throughout the process, stakeholder communication and engagement were continuous through online communication and via three participatory workshops organised in each city. The workshops' objectives were: design future energy scenarios, rank the scenarios using the MCDA applied to the TIMES models results, and develop an action plan for the city energy system transition [33–44].

3. Insights

This section presents the gained insights on modelling EU cities energy system transition obtained in the course of the INSMART project. These are divided in insights related with the energy modelling aspects and insights on data and decision-making that affected the modelling exercise, its outcomes and usability.

3.1. Modelling insights

Throughout the INSMART project it was necessary to balance, on

Table 1
Overview of the INSMART cities and main results.

	Units	Cesena	Évora	Trikala	Nottingham
Location	n.a.	Italy, Emilia Romagna Region	Portugal, Alentejo Region	Greece, Region of Thessaly	United Kingdom, East Midlands Region
Surface	km^2	250	1307	69	75
Population	Number inhabitants	96 758	56 596	62 154	314 300
Situation in Base Year[a]					
Energy residential building consumption in base-year	GJ/dwelling	53.2	16.73	58.42	49.95
Private and public urban mobility energy needs in base-year	GJ/dwelling	89.85	38.21	54.08	80.06
Energy use in city support sectors in base-year	GJ/capita	1.05	1.83	1.45	0.42
Direct CO_2 emissions in base-year	t CO_2/capita	3.71	3.71	1.12	3.60
Main Expected Achievements by 2030 with the adopted Energy Action Plans					
Saved energy (vis-à-vis the reference case) in residential buildings in 2030	GJ/yr. inhabitant	1.40	0.11	0.82	0.13
Saved energy (vis-à-vis the reference case) in transport in 2030	GJ/yr. inhabitant	1.45	0.65	0.13	0.60[c]
Reduction of CO_2 emissions[b] from base year	%	31	22	9	21
Direct CO_2 emissions in 2030[b]	t CO_2/capita	2.50	3.45	0.95	2.57

n.a. – not applicable.
[a] Base year is 2012 for Trikala, 2013 for Cesena and Évora, and 2014 for Nottingham.
[b] Only for INSMART sectors (i.e. transport, buildings, water, wastewater & waste management).
[c] Does not include travelling to work outside the city.

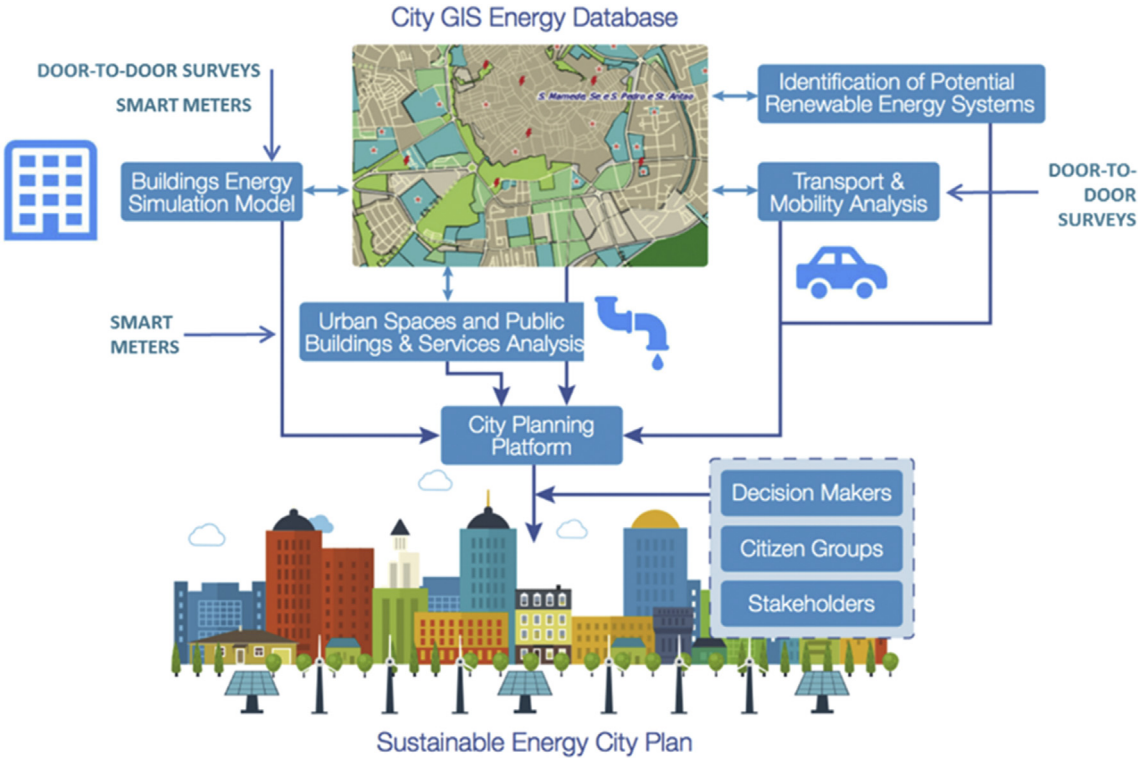

Fig. 1. – Overview of the used approach. Reference: Adapted from Ref. [27].

one hand, the need to explicitly represent all relevant city sectors and activities allowing to effectively communicate the results to stakeholders, and, on the other hand, the availability of data and capacity to manage increased TIMES models' complexity. This balance also exists when using national TIMES models, but at local level there is much better knowledge of the smaller modelled terrain and some simplifications are not accepted by the end-users. For example, in a national TIMES energy system model, services buildings can be modelled differentiating only large and small buildings, whereas at local level further disaggregation is necessary (e.g. commerce, offices, education, health, etc.). Similarly, geographical transparency was found to be paramount. The TIMES city models were disaggregated to allow identification of the basic geographical entities (zones) representing the most suitable geographical distribution of the information for planning purposes (see Fig. 2). A compromise must be reached between political, administrative and spatial boundaries that reflects the impact of the city and its energy sectors whilst fixing the model within the stakeholders' sphere of influence. This was considered fundamental by the municipalities, although it substantially adds to model complexity and results processing, and is hampered by lack of detailed data in some cases. A similar aspect was the necessity to explicitly include all city energy consumption sectors even if they have a low representativeness in the global city energy balance,

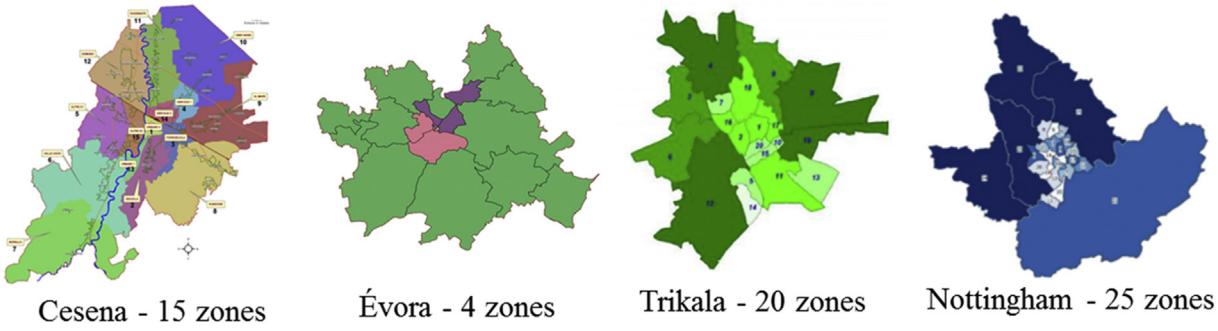

Fig. 2. – Modelled zones for the four cities in INSMART. Reference: [27].

such as the case of buildings managed by the municipality. This level of detail had two benefits: i) allowed the end-user (the municipalities) to use the TIMES model results to support their immediate internal energy objectives including lowering their energy bill, and ii) built capacity of the municipalities by making clear how much of the energy consumption and emissions of their city are under their direct sphere of influence and how much it is not. This partially explains the somewhat modest GHG emission reductions shown in Table 1 for some of the cities (9–31% GHG reductions in 2030 compared to the base-year), which had to do with the focus of the adopted measures for 2030. Whereas the stakeholders of the cities of Cesena and Nottingham ranked higher in the MCDA and in the subsequent action plan measures related with major changes in residential buildings [36,37], and with private transport [37], in the cities of Trikala [39] and Évora [38], the measures selected were mainly within the direct areas of influence of the city (e.g. municipality buildings, public lighting, parking).

Other aspects that were found to be critical were the definition of the city boundaries, how to treat direct GHG emissions from energy imports into the city considered in the TIMES models (e.g. electricity, gasoline, diesel, etc.) and transport flows from people commuting into and oustide the city. In some cases the city stakeholders only wanted to address the urban area, whereas for the case of Évora, the municipality and other stakeholders decided to address both the city proper and its neighbouring rural areas, which are also managed by the same municipality.

It was found that at local level modelling the level of scrutiny of results is much higher than at national model, again since the territory being modelled is better known by the model end-users. Thus, substantial effort should be allocated to create a sense of ownership of results and to communicate them effectively. For the former, techniques such as the co-development approach with the municipalities and city stakeholders adopted for the scenarios development and the MCDA was found to bring much added value as it allowed establishing a communication channel between modelers and the end-users of the model results. The usage of the MCDA to further assess the TIMES models results definitely increased their usability for the cities and allowed validation and correction of model results. Ranking the several options within the MCDA approach increased the awareness of stakeholders on the importance of the results and on the decisions to be taken. The MCDA ranking was iterated in some cities untill consensus was achieved. Regarding communication, a good visualization of results was important, for example by using a GIS for mapping results.

3.2. Insights on data and decision-making for modelling EU cities energgy system transition

Accurate and detailed representation of the energy system is always important, but at local level it is even more fundamental to have city specific data with very fine spatial and temporal resolution. Even though all partner cities had previous worked on energy and climate strategies, it was found that nonetheless they lacked some basic knowledge on current city energy consumption, not only on private buildings and transport, but also on activities that are managed by the municipalities. The information is dispersed, not comparable, and sometimes completely lacking. This was the case for example for quantifying the renewable energy potential in the cities, which was at first not identified as data gap by the municipalities, but was at a later stage found to be very useful, not only to reduce GHG emissions, but also for attracting potential investors. It was also found that the national data sources were not adequate and some national information was missing or inaccurate, such as the UK national datasets relating to energy from buildings, which do not accurately reflecti the energy used in the city. For local level modelling, the following data sources were found to be paramount: surveys on mobility, building stock and energy use in dwellings, smart meter data, GIS for locating energy uses across the modelled zones, and energy certificates. It should be mentioned that some of the data is owned by private companies (e.g. waste, water management) and is not available to the municipality and the modelers. Moreover, the data is available with very different time and space resolutions, which required substantial efforts in harmonizing, interpolation and extrapolation to make the information they provide useful for local energy planning.

At the decision-making level, the INSMART process allowed to demonstrate how the energy system can be affected by urban policy making (especially urban planning). Because the estimated outcomes can be compared with the base-year, it is fairly clear to show to the municipality decision-makers and technicians that the interventions it plans should be reviewed for their impacts on energy. The support and commitment of all involved areas inside the municipalities was found to be a key to success. Only a multi-disciplinary municipality team can identify and establish synergies, may avoid data and functions overlaps, and contribute to better design of policies and instruments. The multi-model approach used in INSMART has provided a rationale for involving such a multi-disciplinary team and the use of methods such as MCDA and engaging diverse groups of external stakeholders enabled convergence around a set of sustainable energy measures.

Moreover, thinking ahead on energy consumption in the cities as an “integrated urban energy system” highlighted new priorities instead of those traditionally taken under municipal management (such as public lighting or buildings managed by the municipalities), which is a challenge for a new generation of local energy policies. Likewise, some national policy areas were found to have lacunas in promoting energy efficiency, for example for the privately rented housing sector. For these dwellings, that consume substantial amounts of energy there is no national specific funding schemes currently available in UK and Portugal.

4. Conclusions

It was found that urban level energy modelling brings with it a new set of challenges. One of the most relevant challenges found was to understand to what extent can cities effectively implement measures leading to energy system transitions and deep decarbonisation, since radical energy system transitions, specially on the energy supply and on industry are out of the city's sphere of influence. Cities can, to some extent, limit the permitting of fossil fuel power plants or energy-intensive industries, but in most cases, such permitting is controlled by national authorities and is located outside of urban areas. Likewise, cities can attract renewable energy investments, but normally not large-scale ones, due to lack of space in their territory. Moreover, cities have limited room to design and implement GHG mitigation policy instruments as taxes, subsidies, cap and trade mechanisms, standards. Despite increasing worldwide cities commitment for ambitious GHG mitigation, in concrete terms, city planners/decision makers are mainly focused on energy consumption of municipality managed buildings, public spaces and public lighting, for which they are directly responsible and for which they must pay a substantial energy bill. Furthermore, the most important criteria considered in urban planning is the wellbeing of citizens, including fostering economic development in the city, boosting employment and attracting residents, and only secondarily (if at all) GHG mitigation is considered. Nonetheless, many urban-related actions can be taken to cope with city specific issues with significant benefits for the GHG emissions reduction, such as allocation of construction permits to new districts or buildings subject to the strict respect of standards, as net zero emissions. Other examples of relevant city actions are changes in school schedule to minimise congestion, closing of some streets to the private mobility options, and/or congestion charges in some area of the city. To promote such actions, cities need to gain better knowledge on their energy system and on the effects of their urban planning actions in the energy footprint. The INSMART approach can be replicated for other cities, eventually making use of more simplified TIMES modelling. Building a TIMES model for a city can be very time consuming and thus options to make this simpler should be considered. The combination of TIMES with MCDA is fairly easy and straight forward to implement. It is extremely important to keep in mind that the usage of such complex modelling tools should be seen as part of a learning process. The experience gained through their implementation may facilitate and support the deployment of local sustainable solutions and decision-making in cities, contributing to the realisation of the Paris Agreement.

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